COMMERCIAL ILLUMINATION

BY

DAVID K. MURAMOTO

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DAVID K. MURAMOTO

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E. H. Freeman
Professor of Electrical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

INTRODUCTION

The lighting requirements for the commercial purposes are not alike. They cover so wide a range as there are great variation of the classes of merchandise exhibited, in arrangement and nature of displays, etc., the study of these are very interesting. In order to make it clear a few important points as to the office and the store are brought out. Then the photometry, the measurement of general illumination, the designing in order to give the practical sides aswell as theoretical side.

STORE AND OFFICE LIGHTING

The general requirements for office lighting are almost alike, for but store are not. In large installations economy of operation is a very live subject. It is of less importance in small places, but should never be ignored. Color diffusion, distribution,unity are all phases which must receive attention.

In a broad sense we may make for any lighting installation the primary demand of a sufficient illumination for careful examination of the goods in the case of store and for the specific work to be done in the case of office. In some kind of stores such as jewelry stores, a brilliant light is necessary for the sake of showing the goods to advantage. The same is not true of other stores handling different kinds of goods. The phrase "sufficient illumination" must therefore be interpreted in each specific case.

The distribution and diffusion of light is the most important. Here, again, no one condition satisfies all requirements. If a piece of goods

is illuminated by light coming equally from all directions it cannot be well discerned. It will appear flat and characterless. A considerable component of directed light is necessary.

Color content of artificial light if another item which must be taken into account in many stores.

The general conditions also require a full appreciation of the importance of the comfort and convenience of the customers. Also it is extremely bad practice to install any office or store lighting system in such a way that a lack of uniformity of illumination is evident. The result should be a unit and it should come from a designed installation which also shows uniformity of purpose and method. In the most successfully lighted stores, the visitor does not see the lighting devices, but entirely forgets that there are such utilities present.

In large stores both direct and indirect fixtures are used. At present the tendency is to the installation of complete lighting units of

totally enclosing type or those formed by incorporating an upper reflecting surface, either opaque or translucent, in combination with a diffusing bowl. It is claimed that this type of fixture when properly used is simple and inexpensive. The most economical units are direct lightings with proper reflector especially in the large stores where the ceilings are high enough to permit proper elevation of fixtures. The major part of the light is thrown down to a rather restricted area, directly below the lamp. Distant lamps are therefore not glaring and only by looking at a sharp angle can an excess light meet the eye.

Photometry is the process of measuring the intensity of the light flux in any given direction or directions. Hence, it is fundamental to all the steps by means of which the lamps are appraised. Its practice and expression of its results require a set of terms in order that the presentation of facts may be scientifically correct and accurate as well as apprehensible to the reader. To avoid complexity and unnecessary steps only a few of them are presented. They are reproduced from the reports of the committee on nomenclature and standards of the Illuminating Engineering Society (1916) and have been established in conference with other societies. They are as follows:

$I =$ the luminous intensity.

Defining equation:

$$I = \frac{dF}{dW}, \text{ hence, } I = \frac{F}{W}$$

$F =$ luminous flux $=$ radiant power evoluted according to its visibility $=$ its capacity to produce the sensation of light.

$W =$ the solid angle.

$E =$ Illumination.

$$E = \frac{dF}{dS}$$

When the illumination is uniform,

$$E = \frac{F}{S}$$

where S is the area of the intercepting surface.

Candle = the unit of luminous intensity maintained by the National Laboratories all civilized Nations.

Candle-power = candle.

Lumen = unit of luminous flux

= flux emitted in a unit solid angle by a point source of one candle-power.

Lamp = a generic term for an artificial source of light.

Primary luminous standard = recognized standard.

Reference standard = a standard calibrated in terms of the unit from either representative or reference standard.

Working standard = any standardized luminous source for daily use in photometry.

Test lamp in a photometer - A lamp to be tested.

Mean spherical candle-power = average candle-power of a lamp in all directions in space.

Hence, candle-power = $\frac{\text{spherical candle-power}}{4\pi}$

THE PHOTOMETER

The photometer consists essentially of a screen to be illuminated, an optical system for observing the effect upon the screen, and a scale for measuring the foot-candles. It is operated by allowing the test lamp and the standard lamp to illuminate the screen simultaneously, while the distances are adjusted until equality of illumination is secured.

METHODS AND TYPE OF PHOTOMETER

There are three distinct methods by which the intensity of light is measured. The foremost of these may be known as the method of direct

comparison by equality of brightness. The second is the flicker method. The third establishes a reading by finding at what distance the light is effective in illuminating a printed paper for reading. It will be seen that the light flux is considered here without regard to color. Where this latter is necessary, there other methods of approaching the problems more scientifically although the flicker method could be adopted to take care of just such difficulties.

For simplicity and satisfaction, the direct comparison of the test lamp with a standard by equality of brightness is generally used. Among many different makes the Sharp-Millar Photometer or the Universal Photometer is a well known and much used instrument. Although there came out recently many newer types which can be operated without any scientific knowledge.

In Figure V there are shown a rough sketch of "Sharp-Millar" in connection with the scheme. The comparison lamp (L) rests upon a rider which can be drawn back and forth in the box by turning

a knob (K) which turns the drum. Light from the comparison lamp passes through openings in the barrier screen (S). (G) is green glass which changes the color of the light from the lamp. (P) receives diffused light from this source and in turn transmits it to the eye-piece (E). In order to secure a greater range of illumination absorbing screen (A) are provided which may be moved into a position so as to transmit 10 and 1.0 percent respectively of the incident light.

CALIBRATION OF THE INSTRUMENT

In the Fig. V, the scheme of connection is shown with a set-up of the instrument and a "dark box". This box has two openings at (M) and (O) is of 6" x 6" x 30" outside dimensions, with upper covering extended beyond (M) as shown, in order that the place for the socket may be conveniently located. Distance between (O) and standard lamp (L_s) is d. For this particular purpose d is made to equal to $\sqrt{10}$ feet = 31.6 ft.

The elbow (O) is inserted in such a way that the center lines of both box and elbow will coincide.

Also in the scheme:

L_s is standard lamp.

V, voltmeter (0 - 150 volts)

E_1, storage battery having voltage from
110 or more.

R_1, Rheostat.

R, Rheostat.

A, Milliammeter or voltmeter.

E, Batteries - 5-6 volts.

OPERATION

Adjust R_1 so that the current flow will be a minimum, connect a voltmeter across the lamp (L_s) terminals and increase the current until the voltmeter reads 110 volts. Measure distance, d. Then from inverse law, we have:

$$E = \frac{I}{d^2} \text{ foot-candles,}$$

where I is the candle-power in the direction of the screen, and E = foot-candles.

Since the instrument is direct reading, we have to adjust the rheostat (R) and turn the knob (K) so that it reads exactly E.

For example, suppose we have:

$$d = 3.16 \text{ ft.}$$

$$I = 32 \text{ candle-power,}$$

then,

$$E = \frac{32}{3.16^2} = \frac{32}{10.} = 3.2 \text{ foot-candles.}$$

These three quantities, d, I and E, are known and can not be altered. Therefore, in order to secure equality of illumination is to adjust Rheostat (R). When this is done satisfactorily, read the ammeter or the voltmeter (A) and record it for the future use.

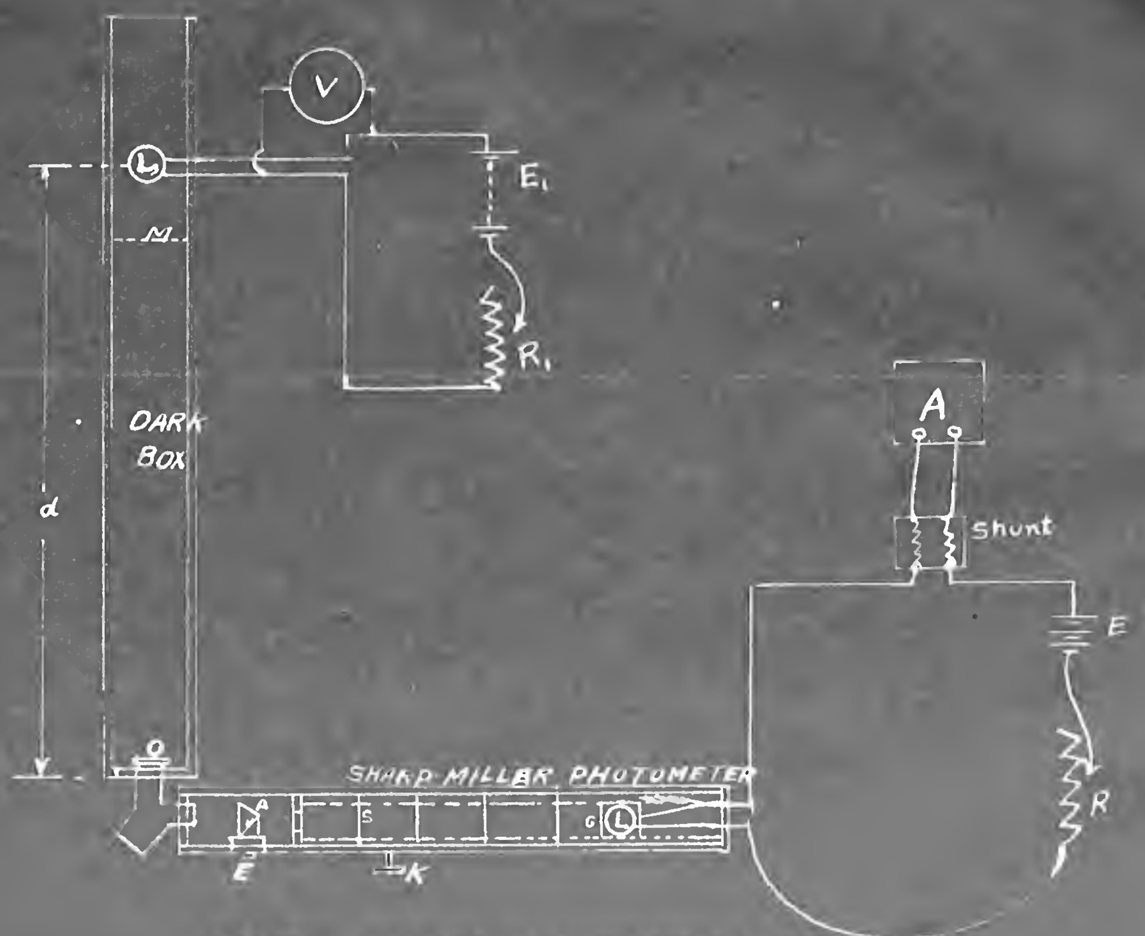


FIG V SCHEME OF CONNECTIONS FOR CALIBRATION OF PHOTOMETER LAMP, L.

ILLUMINATION MEASUREMENTS

To determine the intensity and the distribution of the illumination due to a lighting installation, surveys have been made in the Drafting room on the fifth floor, Electrical lecture room, and Machine Shop of Armour Institute of Technology. In making these tests the area, in each case, was divided up into small squares or rectangles as shown in the diagrams, and measurements made of the intensity of the illumination at the centers of each section. As the distribution of lamps in the first two rooms, drafting room and the electrical lecture room are very well made, and a quarter of a room was measured, it being assumed that the result of each quarter is like every other quarter.

The method of laying off a room into sections for a test is shown in the Figs. II and IV. In the former case it is divided into 56 sections and has 4 lamps equally distributed, and located at A, B, C and D, as shown. It is clear from the picture that the intensity of the light at 1 and 7 are equal and that at 2 and 6 are also equal, etc., that

is, the four-quarters of the rooms are similar. Therefore, if we take readings in one-fourth of the room, bounded by 1 - 4 - 34 - 30, we can obtain the average intensity for the room.

OPERATION OF THE INSTRUMENT

The scheme of connection is the same as Fig. V, excepting the connection of L_s with "dark box". The place of L_s is taken by the general illumination which is to be measured, and the elbow should be set upright so that the reflecting surface (O) will be parallel to the floor surface. The operation of the instrument is so simple that it scarcely needs to be explained here, but as a matter of formality, I shall mention a few steps.

Procedure:-

1. - Set instrument at right place.

2. Adjust the resistance so that the ammeter indicates the value recorded in the calibration of the lamp, and keep it constant.

3. Then read the voltage (voltmeter is not shown in the figure) of the general lighting circuit.

4. Read the instrument after equality of illumination is obtained. This is done by turning the knot (K) back and forth as before.

The adjustment of the ammeter and the reading of the voltage are equally important, because the percentage variations in candle-power, lumens and resistance with variations in voltage is more than porportional. When, for instance, a lamp is run at too high a voltage, the candle-power and light flux are increased, (although this is done at the expense of the life). The percentage variation of carbon lamps is still greater than that of the Mazda lamps and if this is plotted against variable voltage the curve obtained is somewhat concave upward.

The characteristic curves of incandescent lamps are found in Standard Handbook, pages 1091-1092, also in other books on illumination. These relations are also expressed in the equation:

$$\frac{V_1}{V_2} = \left(\frac{e_1}{e_2}\right)^K$$

where V_1 and V_2 are voltages, and e_1 and e_2 are

corresponding candle-power. For Mazda lamps K is approximately equal to 3.61.

COEFFICIENT OF UTILIZATION - DIRECT METHOD

When the average value of the intensity of illumination is found the calculation to find the factor of utilization is simple. But, it should be kept in mind that the result would not be accurate unless the spacing is very short. The coefficient of utilization is:

$$\frac{\text{Total light flux output}}{\text{Total light flux input}}$$

Total light flux output is the average intensity of illumination of the room multiplied by the area of the room. Total light flux input is equal to the mean spherical candle-power of each lamp, times 4π, times number of lamps in the same room.

DATA No. 1.

Electricity-Lecture Room

	Readings						Corrected Value				
Station No.	Volts	E	No.	Volts	E	Station No.	Volt	E	No.	Volts	E
1	114.5	1.25	25	112.5	2.4	1	110	1.24	25	110	2.38
2	112.	1.41	26	113.	2.85	2		1.4	26		2.83
3	113.	1.2	27	111.	3.25	3		1.19	27		3.24
4	113.	1.05	28	111.	2.21	4		1.04	28		2.21
5	113.	1.2	29	111.	1.93	5		1.19	29		1.93
6	112.	1.41	30	111.	2.2	6		1.4	30		2.2
7	114.5	1.25	31	111.	1.3	7		1.24	31		1.3
8	114.	2.14	32	111.	1.64	8		2.12	32		1.64
9	113.8	3.7				9		3.68			
10	112.5	2.9				10		2.89			
11	112.5	1.87				11		1.88			
12	112.5	2.9				12		2.89			
13	113.8	3.7				13		3.68			
14	114.	2.14				14		2.12			
15	114.	2.73				15		2.715			
16	114.	4.8				16		4.77			
17	112.5	2.7				17		2.68			
18	112.5	2.3				18		2.29			
19	112.5	2.7				19		2.68			
20	114.	4.8				20		4.77			
21	114.	2.73				21		2.715			
22	111.	2.21				22		2.21			
23	111.	3.25				23		3.25			
24	113.	2.4				24		2.38			

Station No. indicates points where measurements were taken and E, in foot-candles.

DATA No. 2.

Drafting Room.

Point No.	Ft.-Candle E	Point No.	Ft.-Candle	Point No.	Ft.-Candle
1	3.25	21	4.6	41	7.1
2	3.61	22	7.	42	8.2
3	3.8	23	6.69	43	8.2
4	4.1	24	5.96	44	7.7
5	4.71	25	7.09	45	9.5
6	4.75	26	8.35	46	8.9
7	4.4	27	7.7	47	9.
8	4.6	28	8.05	48	9.9
9	4.4	29	7.7	49	9.
10	4.75	30	8.35	50	8.9
11	4.71	31	7.09	51	9.5
12	4.1	32	5.96	52	7.7
13	3.8	33	6.69	53	8.2
14	3.61	34	7.	54	8.2
15	3.25	35	4.6	55	7.1

DATA No. 2.

(continued)

Point No.	Ft.-Candle E	Point No.	Ft.-Candle	Point No.	Ft.-Candle
61	5.8	81	6.1	101	6.4
62	7.5	82	8.1	102	8.
63	7.4	83	7.8	103	7.9
64	7.8	84	8.1	104	8.2
65	9.2	85	9.2	105	10.
66	8.3	86	8.3	106	10.
67	8.6	87	9.6	107	11.
68	13.2	88	13.4	108	11.
69	8.6	89	9.6	109	11.
70	8.3	90	8.3	110	10.
71	9.2	91	9.2	111	10.
72	7.8	92	8.1	112	8.2
73	7.4	93	7.8	113	7.9
74	7.5	94	8.1	114	8.
75	5.8	95	6.1	115	6.4

DATA No. 2.

(continued)

Point No.	Foot-Candle
121	7.
122	11.5
123	9.4
124	9.5
125	13.5
126	9.9
127	9.
128	14.
129	9.
130	9.9
131	13.5
132	9.5
133	9.4
134	11.5
135	7.

DATA No. 3.

Machine Shop - Machinery Hall

Point	Ft.-Candle	Point	Ft.-Candle
1	6.	16	22.
2	4.5	17	4.5
3	15.2	18	13.
4	5.2	19	8.
5	7.9	20	4.
6	4.4	21	5.
7	7.	22	4.5
8	12.	23	10.
9	8.7	24	7.
10	17.	25	8.
11	6.	26	12.
12	7.	27	4.
13	7.	28	3.
14	5.	29	8.
15	6.1	30	11.

RESULT OF MEASUREMENTS

Room	Lamp	Reflector	Kind of lighting	Average foot-candle	Area	Total flux input	Total flux output	Coefficient of utilization.
Electricity Lecture Room	4-100 c.p. lamps	Glass deep bowl	General	2.38	620 sq.ft.	4020 lumens	1475 lumens	.371
Drafting Room - 5th Floor	25-200 c.p. lamps	R.L.M. Dome	General	9.9 on table top and 8. on entire floor	3111 sq.ft.	50240 lumens	24888 lumens	.492
Machine Shop	58-4watt lamp. 12-200 c.p. lamp.	No. ref. deep bowl.	Combination of General and Local	7.	2920 sq.ft.			

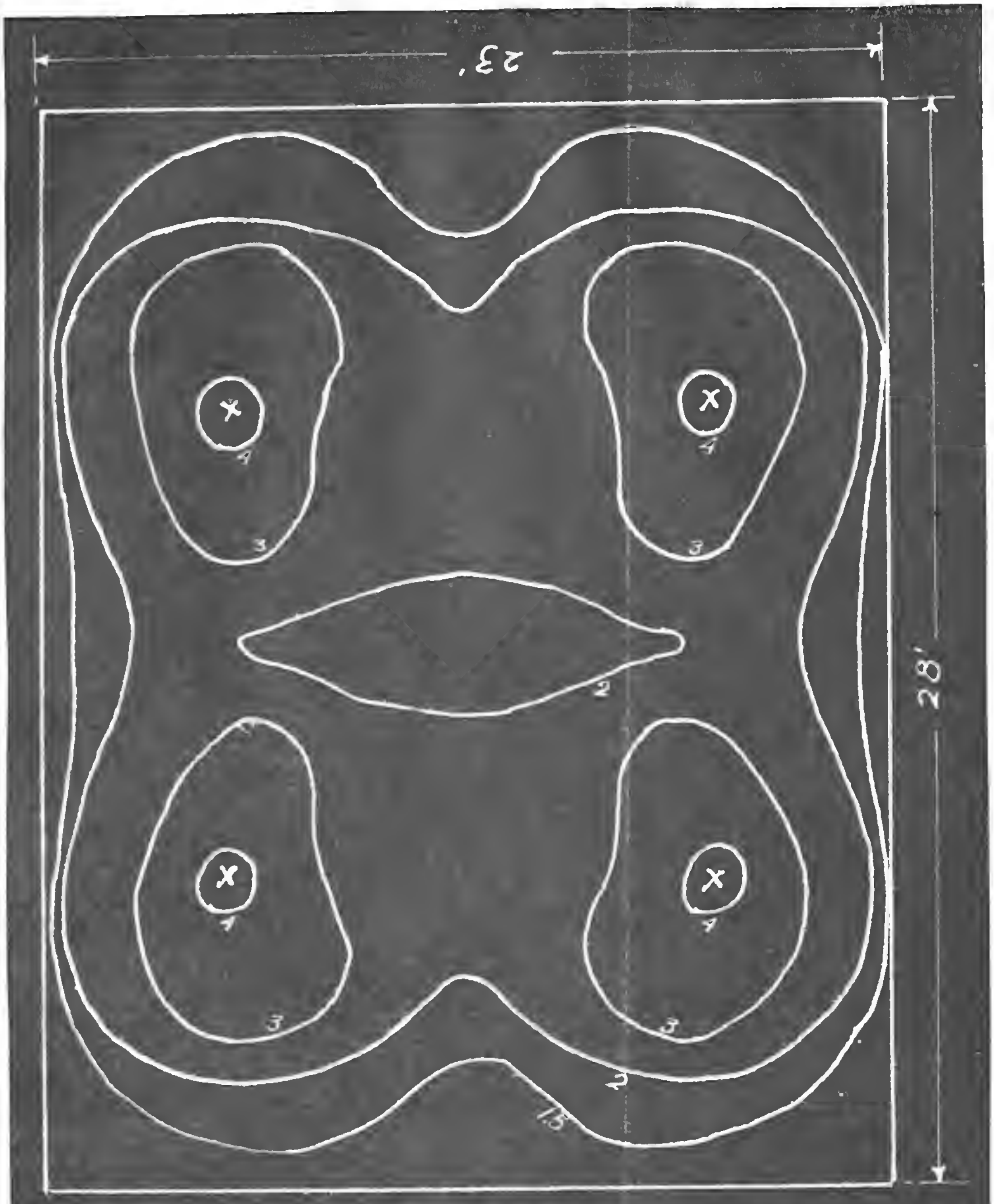


FIG. I TOPOGRAPHIC VIEW OF THE DISTRIBUTION OF LIGHT. ELECTRICITY-LECTURE ROOM, ARM. INST. OF TECH. BY D.K.M.

Numbers indicate lumens in Ft.-Candles.

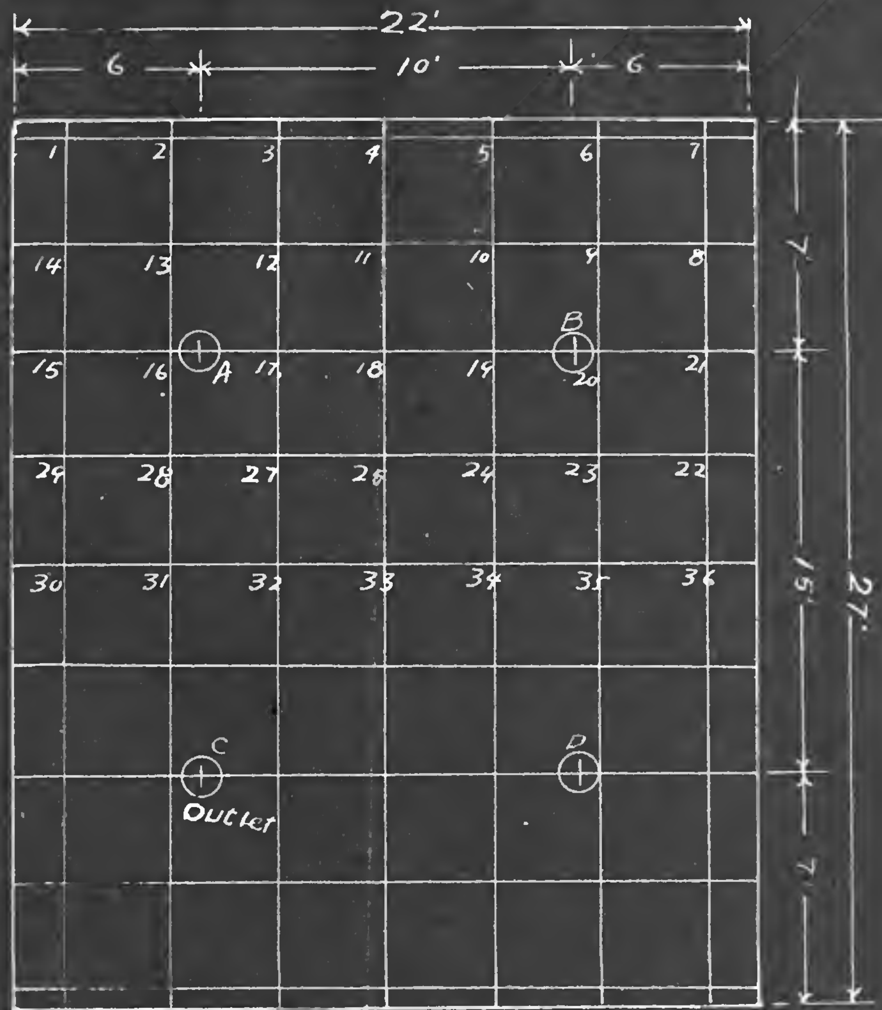
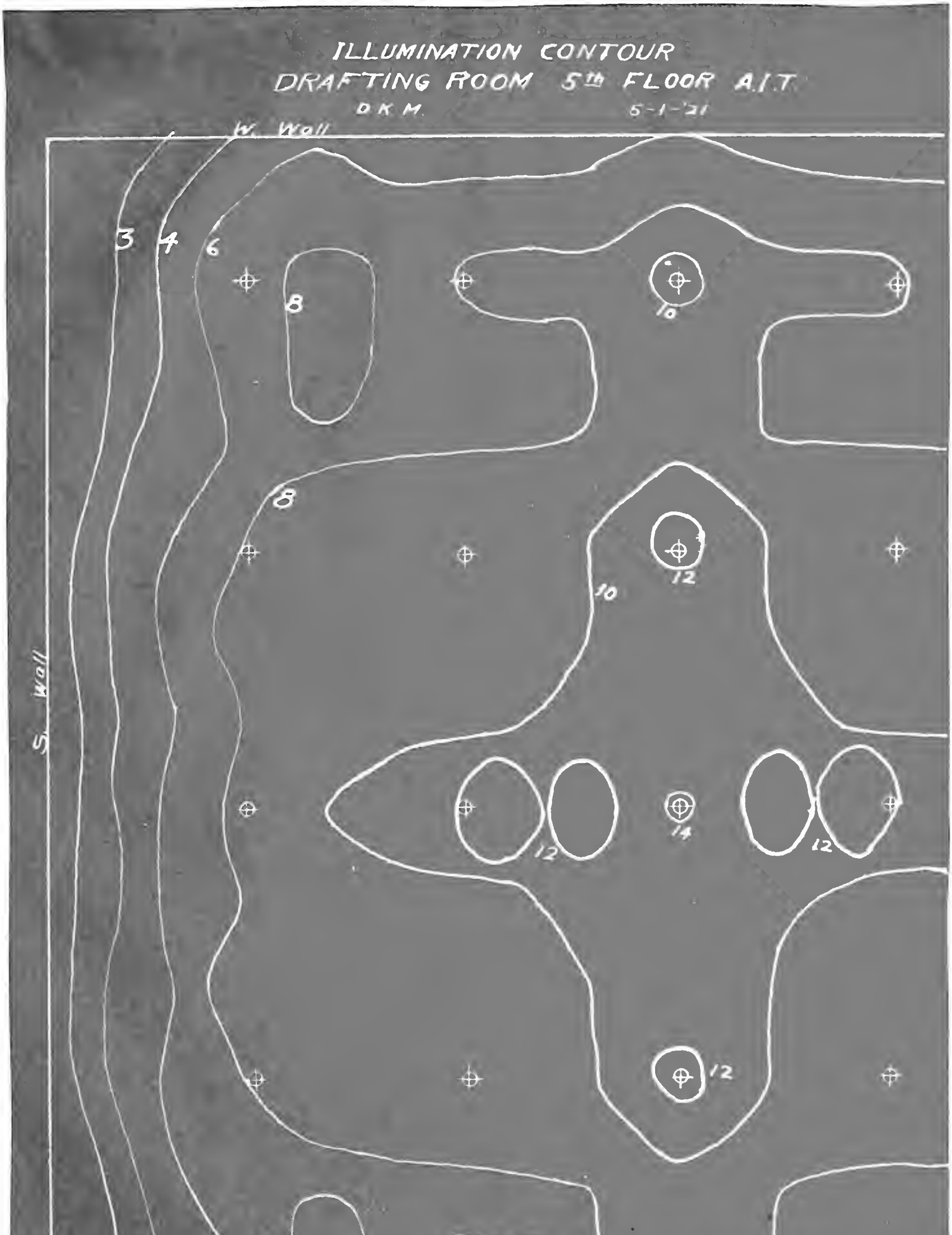


FIG II ELECTRICITY - LECTURE ROOM, A.I.T.
NUMBERS IN THE SQUARES INDICATE
POINTS WHERE READING WAS TAKEN


ILLUMINATION CONTOUR
DRAFTING ROOM 5th FLOOR A.I.T.
D.K.M.
5-1-'21
W. Wall
S. Wall
3
4
6
8
8
10
10
12
12
12
12
14
FIG III

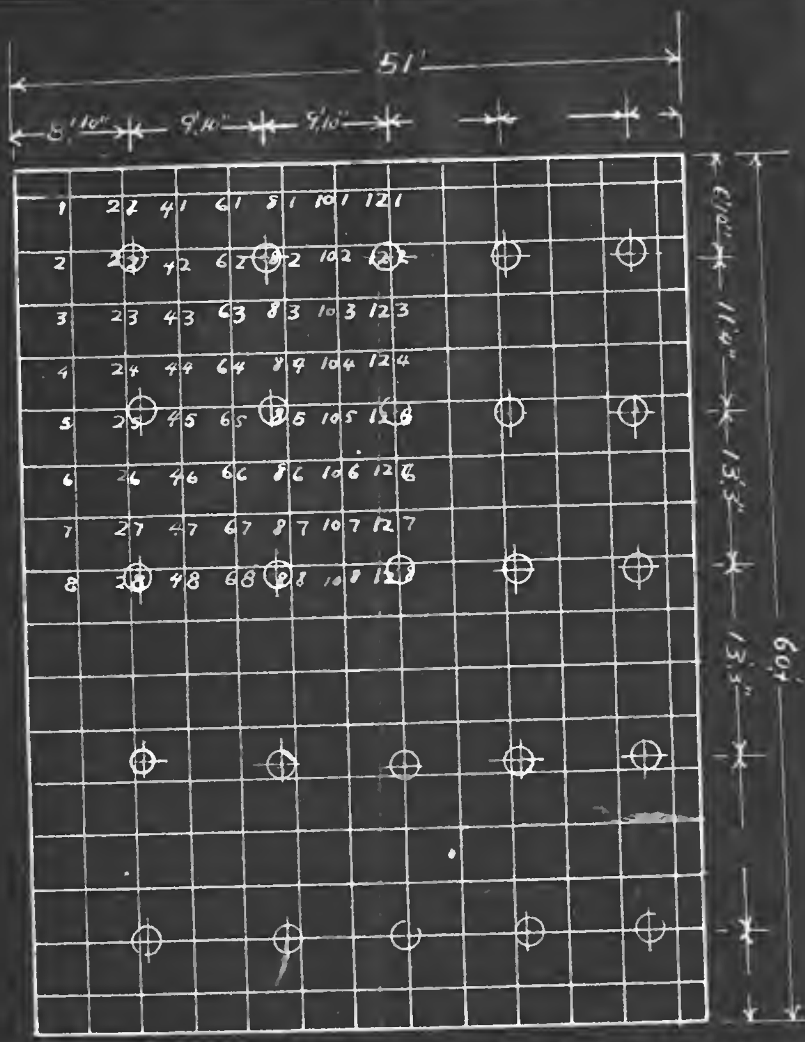


FIG IV DRAFTING ROOM. 5th FLOOR
MAIN HALL A.I.T.
NUMERALS INDICATE POITS AT
WHICH THE MEASUREMENTS WERE TAKEN

DESIGN OF ILLUMINATION

In designing illumination, there are certain steps which one must take in developing the calculations. The questions may be arranged in the following order:

How much illumination is required?

How much light flux is needed in order to produce this light?

Total output of the lamps in lumens?

Distribution of units, and how?

Power rating?

Mr. Earl A. Anderson, in his data of Illumination Design Bulletin 41, gives the method of determining various factors and of calculation in the following manner:

1. The decision as to the foot-candles of illumination required.

2. The selection of lighting units, best adopted to the particular requirements.

3. The determination of outlet locations, mounting height, and number of lighting units required.

4. The selection of proper size of lamp to provide the foot-candles desired.

ILLUMINATION REQUIREMENTS

As a result of a large number of tests which have been made in all kinds of rooms, by various societies and manufacturers, we are well provided with tables giving the amount of illumination needed for every different kind of service. Among a large number of tables, the latest table compiled by the National Lamp Works is most reliable.

THE SELECTION OF LIGHTING UNITS

The selection of lighting units depends largely upon the personal taste and also upon the particular requirement.

Under this heading came many factors such as glare, direct and reflected, shadows maintenance, good appearance and a great many others. In general, the direct lighting serves well and most economical. The lamps being used in commercial illumination are Mazda, Type (C). The reflectors used in these fields have large variety. The Bulletin No. 41 of National

Lamp Works gives a very good idea of particular uses of the outfit.

DETERMINING OUTLETS, MOUNTING HEIGHTS AND NUMBER OF UNITS.

Measure the room-length, width and height of ceiling, and calculate area of the room. Determine number of outlets. Area in square foot per outlet

$$= \frac{\text{Area of the room in sq.-ft.}}{\text{Number of outlet.}}$$

Permissible distance between outlets and mounting height have definite relations between them. This is given in table No. 2, of the same Bulletin, or maybe found any other books on illumination.

After the spacing is determined, locate the outlets, and the diagram of the floor, giving due allowance of symmetry of locations.

Lamp lumens per outlet =

$$\frac{\text{Foot-candle x depreciation factor}}{\text{Coefficient of Utilization}}$$

$$\text{x area sq.-ft. per outlet.}$$

The depreciation factor is taken as 1.3 and 1.5 if the room is dirty. The next step is to

find the room index and color of walls and ceiling in order to get coefficient of utilization. The room index may be found by the following equation:

$$\text{Room index} = \frac{\text{Dimension of room}}{\text{Height of ceiling}}$$

or by consulting the table V of the Bulletin. A ceiling is an effective reflector if it has a light tint. The reflective coefficients vary from 25 percent to 80 percent. Walls are another agency capable of being utilized to aid in directing light on a horizontal plane, but comparatively speaking, the factor of the wall is many times smaller than that of the ceiling. The combined reflective coefficient may be found experimentally or in tables, these are given in the table IV. If the colors of ceiling and walls are radically different, there is no way of finding them, but using judgment to get at it.

DESIGN OF ILLUMINATION

DYNAMO LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Dimensions of the room:-

Length = 63.5 feet

Width = 53.5 "

Height = 14.2 "

Area = 3400 sq. ft.

Number of outlets = 20.

Height of lamps from the floor = 12 ft.

Spacing (6.7 feet next to wall
(13.2 feet S.N.
(12.7 feet E.W.

Illumination in foot candles = 6.

Utilization factor found to be .52.

Depreciation factor = 1.3.

Square feet per outlet = $\frac{3400}{20}$ = 170.

Room index of (50, 60, 12) is 2.5

Lamp lumens per outlet =

$$\frac{6 \times 1.3 \times 170}{.52} = 2550 \text{ foot-candles.}$$

Looking at table VI we find Mazda lamps 150 watts and 200 watts which come nearly to meet the above requirements since the place like that gets dirty quickly, we add a small factor to the depreciation and choose 200 watt lamp which gives 3100 foot candles per outlet.

$$\text{Then lumens per unit area} = \frac{6 \times 3100}{2550}$$

$$= 7.2 \text{ foot candles.}$$

Checking this value with table VII under the following values:

Area = 170 (not shown), 200 watts, 3100 foot candles, and the factor .52 (not shown) we get the value between 6.6 and 7.3.

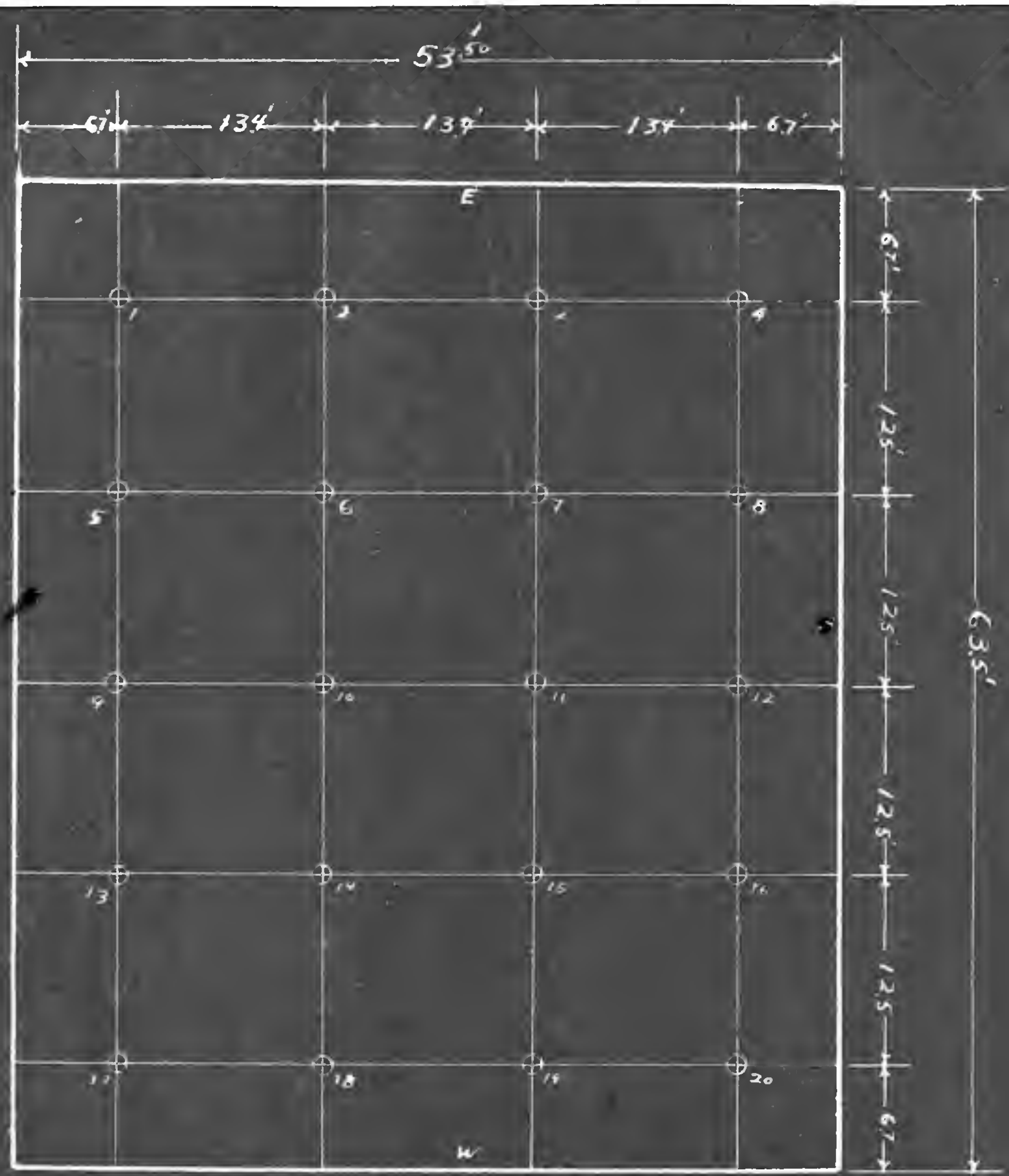


FIG VI. DYNAMO LABORATORY SHOWING LOCATION OF LAMPS

DISCUSSION

There are several different methods by which an installation for the illumination may be designed. The most well known methods are point-by-point method, and graphical method, and each of these methods may be divided into several subordinate methods. Recently,the charts for rapid calculation were invented by some Engineers. One of these is by Mr. I. W. Gross. Whatsoever method is used in calculations it is based upon the fundamental equation $F = \frac{\text{Cos.}^3\theta \times I}{H^2}$ (ft.-candles). This law is called the cosine law and is derived from

$$F = \frac{I}{r^2}.$$

When we are provided with the curve of an outfit, it is most accurate and rapid, in a long run, to plot the curve, showing relations between the horizontal distances and the intensity of light making the height is constant. Make two or more curves with different heights. After this has been done divide the room into sections as before. Now if we have number of lamps in the room, the inten-

sity of illumination at a point will be:

$$E = K_1 I_1 + K_2 I_2 + K_3 I_3 --- + K_n I_n$$

where value of K_n vary from 0 to $\frac{1}{H^2}$.

To simplify the process and reduce it as much as possible, we reduce to a minimum the stations to be considered by studying the symmetry of the case. For example take Fig. IV there is shown a room 51' x 60' in which it has been decided to place twenty-five lamps, for instance, at the points as shown.

Examining this figure, it is evident that derivation of illumination data for a small part of the working plane will give information for the whole room. Choosing stations having four-foot spacing, we will number them from 1 to 8, as shown, beginning in one corner of the room and running about half-way across the end. The stations of the row are numbered from 22 to 28 for the third row we have 41 to 48, etc. (this arrangement may be made in any other convenient way). Now, without following the analysis through in detail, we can

assert that all that is required is to secure data for that part of the working plane included in the triangle whose vertices lie at stations number 1, 8 and 128, with, perhaps, a few special points like lamps on the next row. This involves a list of 36 stations. The calculation of any one of these necessitates an estimate of the illumination at that point by each of several lamps, numbering from 3 to 7, in this particular instance. It is very probable, however, that we shall find a few duplicate values in this list, as, for example, the two series 42, 43 -- compared with 62, 63 --. Certain other identities might be prophesied after a little investigation.

Going back to our starting point, we have a room 53.5 feet by 63.5 feet with ceiling 12 feet high. A working plane, say, 30 inches, above floor, and suspension of same undetermined distance from the ceiling. The lamps used are 200-watt Mazdas with the standard dome reflector, enameled. Light flux amounting to about 6 to 7 lumens per sq. ft. is found in the table. We will try out three dif-

ferent heights of suspension, namely, distances above the working plane of 11, 10 and 9 ft.

By means of the use of KI, in which K may be expressed in terms of (d) which is variable, the first steps are taken by preparing a table of values of the illumination by lamps for series of points along a straight line on the working plane, beginning directly underneath the lamp, and extending to a distance such that the vertical components become of negligible value. This gives a curve irregular, but looks somewhat like monotone curve. We have then, three curves similar, but different in values.

It now remains to compound these individual effects for successive stations. It is convenient to do so by means of tabulated distances and their corresponding values of illumination.